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Physica C 408–410 (2004) 228–229
PHYSICA C
www.elsevier.com/locate/physc

Elementary excitations in high-T_c cuprates: kink and resonance peak

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Abstract

Assuming the exchange of antiferromagnetic spin fluctuations as the Cooper pairing mechanism we calculate the kink-like change of the quasiparticle velocity seen by ARPES resulting from the coupling to spin fluctuations and the resonance peak seen in inelastic neutron scattering experiments. Both a pronounced kink and a resonance peak are obtained only for hole-doped, but not for electron-doped cuprates. Furthermore the kink shows a strong anisotropy in momentum space. This is characteristically different from what is expected due to electron-phonon interaction.

PACS: 74.72.−h; 74.20.−Mn; 74.25.Ha
Keywords: Electronic correlations; Electron-doped cuprates

It is well-known that the understanding of the elementary excitations in conventional superconductors measured by tunneling spectroscopy played the crucial role in accepting the picture of electron-phonon-mediated Cooper-pairing [1]. Thus, elementary excitations in the cuprates are of central interest in order to learn more about the pairing mechanism for superconductivity. In particular, one expects that due to the presence of antiferromagnetic spin fluctuations a strong renormalization of the spectral density resulting in a kink-like change of the quasiparticle velocity may occur. Recent developments in angle-resolved photoemission spectroscopy (ARPES) allow us to study the elementary excitations directly and in much detail. This is important, since the coupling of the quasiparticles to spin fluctuations varies at different parts of the BZ. Also important for analyzing the pairing mechanism in high-T_c superconductors is the understanding of the spin-excitation spectrum $\mathrm{Im}\,\chi(\mathbf{q},\omega)$ as observed by inelastic neutron scattering (INS). Of particular interest is the interdependence of the elementary excitations with spin excitations: INS experiments show the appearance of a resonance peak at ω_{res} only for hole-doped cuprates and only below T_c [2] and find a constant ratio of $\omega_{\mathrm{res}}/T_c \simeq 5.4$.

In this paper, we use an electronic theory for the spin susceptibility and for the Cooper-pairing via the exchange of antiferromagnetic spin fluctuations in order to analyze the consequences on the resonance peak and on the spectral density. For this purpose we solve self-consistently the generalized Eliashberg equations [3] within the FLEX approximation [4]. For a description of a single CuO_2-plane we employ the two-dimensional one-band Hubbard model

$$H = -\sum_{\langle ij\rangle\sigma} t_{ij}(c^+_{i\sigma}c_{j\sigma} + c^+_{j\sigma}c_{i\sigma}) + U\sum_i n_{i\uparrow}n_{i\downarrow},$$

where $c^+_{i\sigma}$ creates an electron with spin σ on site i, U denotes the on-site Coulomb interaction, and t_{ij} is the hopping integral. After diagonalization of the first term, one arrives at the bare tight-binding dispersion

$$\epsilon_{\mathbf{k}} = -2t[\cos k_x + \cos k_y - 2t'\cos k_x \cos k_y - \mu/2].$$

Here, t is the nearest neighbor hopping energy, t' denotes the ratio of next-nearest neighbor to nearest neighbor hopping energy, and μ is the chemical potential. Note that in the case of electron doping the electrons occupy

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doi:10.1016/j.physc.2004.02.093